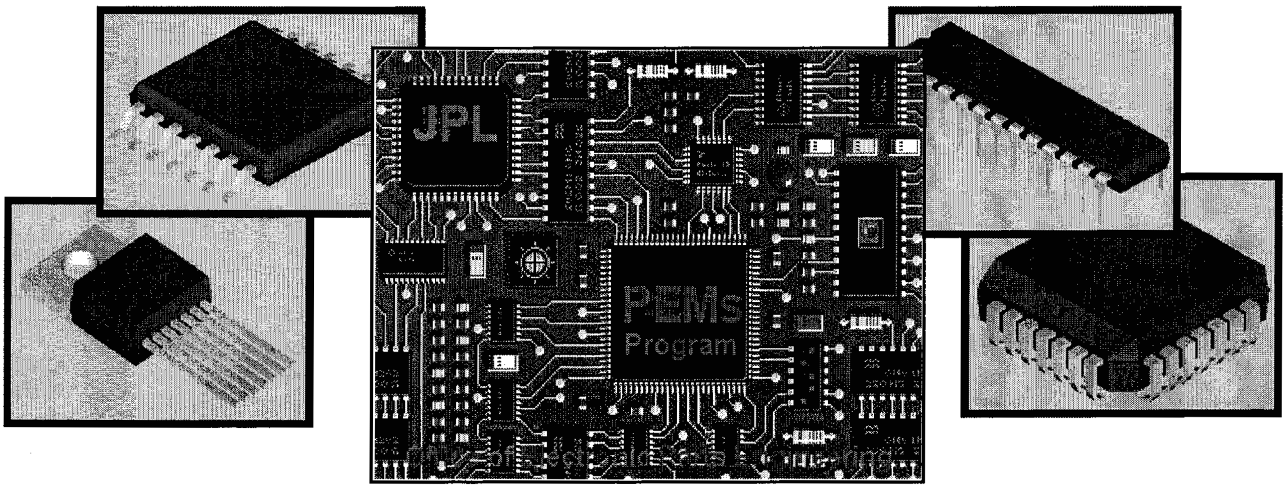
Plastic Encapsulated Microcircuits (PEMs) Reliability/Usage Guidelines For Space Applications



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Disclaimer

The information and data contained herein have been compiled from JPL technical reports, investigations, failure analysis, and from material published by manufacturers, suppliers, and PEM users. The material in this guide is intended to be used for *reference* purposes. Use of this material, without the help of a PEM specialist, can lead to the misuse of plastic parts and may result in a part failure.

The user is further cautioned that the information contained herein may not be used in lieu of contractually cited references and specifications. The information herein is subject to change.

Preface

It is reported by some users and has been demonstrated by others via testing and qualification that the quality and reliability of plastic-encapsulated microcircuits (PEMs) manufactured today are excellent in commercial applications and closely equivalent, and in some cases superior to their hermetic counterparts. However, the key to reliable use of PEMs in *other* than commercial applications, for which they were intended, is gained by matching the capabilities of PEMs to the application environment as much as possible, knowing and understanding their performance/physical limitations, and in performing *all* the appropriate risk mitigation measures.

The purpose of this guide is to assist in mitigating the risk when using PEMs without providing any guarantee that plastic parts will work in all Space applications. It is believed that some amount of risk mitigation can always be accomplished and in some special cases adequate insurance can be given against failure. There are things beyond testing and qualification of PEMs that can increase their reliability (confidence level). These include the proper design of a part into its application, applying part derating where possible, performing comprehensive testing and qualification of the end circuit card or assembly, and using ruggedization protection if warranted. These viable risk mitigation techniques are outside the scope of this guide and are not discussed.

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Section 1
Introduction to Plastic Encapsulated Microcircuits (PEMs)

Plastic Encapsulated Microcircuits (PEMs) are gaining acceptance over traditional ceramic parts in avionics, telecommunications, military, and space applications due to advantages in size, weight, cost, availability, performance, and state of-the-art technology and design. For space applications, economic considerations encourage the use of plastic parts as a means to both reduce cost and shorten design cycle times. However, to the well-informed user, the risk of using PEMs in any high-reliability application is considered high for reasons that will be discussed in the sections that follow.

There are inherent and fundamental differences between conventional hermetic and plastic packaged semiconductors. The confidence and assurance developed for hermetic devices does not automatically apply to plastic packaged devices. However, there are apparent advantages of plastic packages over hermetic. Since there is no internal cavity in plastic, and all internal parts are supported by rigid plastic material, one can expect improved performance under severe shock and vibration conditions. In addition there can be no internal moving of particles from solder, wires, sealing glass, etc. Also the problems of internal lead wire sag, permitting the shorting of wires to each other or to the edge of the silicon chip is obviated.

Plastics are generally low temperature materials compared to glasses and ceramics. It is generally preferred to restrict the temperature of sensitive semiconductors during packaging. Although plastics are not good heat conductors, they are better than nothing at all. Finally, plastics offer the advantage to the manufacture because of the flexibility in using one material for several packaging configurations.

The plastic material most often used is epoxy base resin and there are numerous formulations used by manufacturers based on their properties and how well they behave under testing and reliability qualification. One important property is ionic purity, which is considered important for device reliability. Additive getters are used to remove mobile ionics and to provide high tensile strength to eliminate popcorning. There are numerous properties upon which Epoxy Molding Compounds (EMCs) are rated and used in selection by a manufacturer. Even though the different manufacturers' objectives are usually the same (high device/package reliability and performance), the EMCs used are typically different because of their varying chip designs, semiconductor processes, assembly equipment, reliability test, and qualification methods and results.

Section 2
Outgassing of Plastic Packages

Historically, outgassing testing was developed to qualify any plastic and organic materials which in the vacuum of space could outgas volatile materials that could condense on sensitive optical surfaces. Today the use of PEMs in space warrants knowing the outgassing properties of PEMs because of the various molding compounds used by different manufacturers in the fabrication of PEMs. The plastic molding compound is a complex and typically proprietary formulation of a specific encapsulating resin and various types of additives, which provide the desired properties for the packaged device. Formulations can include epoxy resin, hardening compounds, accelerators, fillers, flame retardants, couplers, stress relief additives, mold release additives, coloring, and ion–getters among others. If any of the material outgases when exposed to a vacuum and/or heat, it may compromise operation and reliability of sensitive optics or sensors. Outgassing testing is used to identify and quantify volatiles being emitted from PEM samples according to an accepted standard such as ASTM E595. The parameters measured for this standard are the total mass loss (TML), collected volatile condensable materials (CVCM), and the water vapor regained (WVR). Since molding formulations are continually changing the outgassing test should be used to monitor and or qualify packages to insure their suitability in critical space applications.

An example of outgassing test results can be found in Figure 2-1 below.

Plastic Packages Outgassing Data

Material	MCR			7612382FBA, E24, DA28F016SV, K8055, U6240332			AM28F020-150PC, 9618FBB			CSI, CAT28F020F, 1-15 09550B		
Part	Motorola SCR			Intel 16 M Flash Memory			AMD 2M Flash Memory			Catalyst 2M Flash Memory		
Sample No.	5	6		7	8	a	9	10		11	24	
WT. Loss %	0.45	0.46	0.45	0.23	0.22	0.22	0.41	0.45	0.43	0.40	0.41	0.40
Water Vapor Recovered, WVR,	0.28	0.25	0.26	0.14	0.11	0.12	0.19	0.17	0.18	0.21	0.18	0.19
%TML (WT, LOSS-WVR) %	0.17	0.21	0.19	0.09	0.11	0.10	0.22	0.28	0.25	0.19	0.23	0.21
CVCM %	0.04	0.08	0.06	0.02	0.01	0.01	0.03	0.05	0.04	0.04	0.04	0.04
DEPOSIT on CP	Opaque			Negligible			Opaque			Opaque		
FTIR Results	Amine cured epoxy			Anhydride cured epoxy			Amine cured epoxy			Amine cured epoxy		

Conclusion: All materials passed . These tests are suited for lot-to-lot comparisons, tracking manufacturing continuity/changes, and measuring absorbed moisture at a known environment.

Figure 2-1. Example of outgassing test results.

Section 3
Moisture Absorption of Plastic Packages

Historically, one of the greatest concerns in PEMs reliability was due to the inherently hygroscopic and absorptive nature of the epoxy molding materials used to encapsulate PEMs.

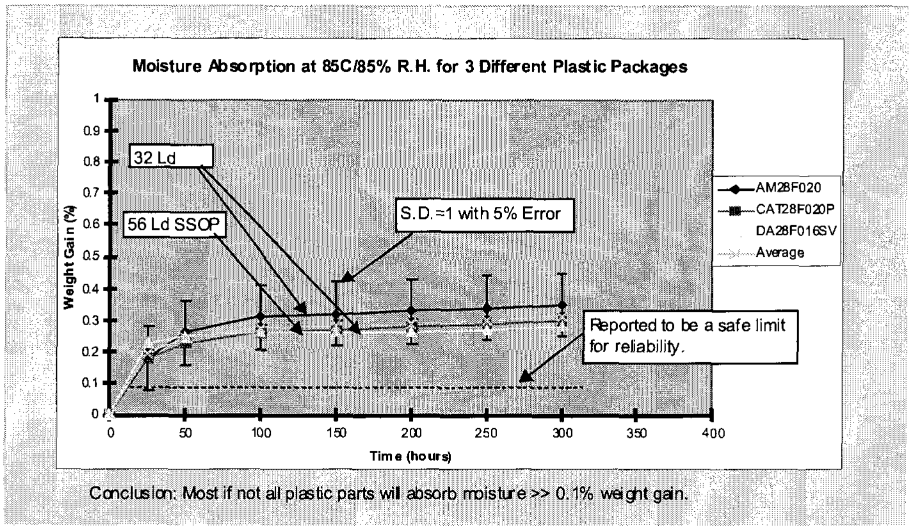
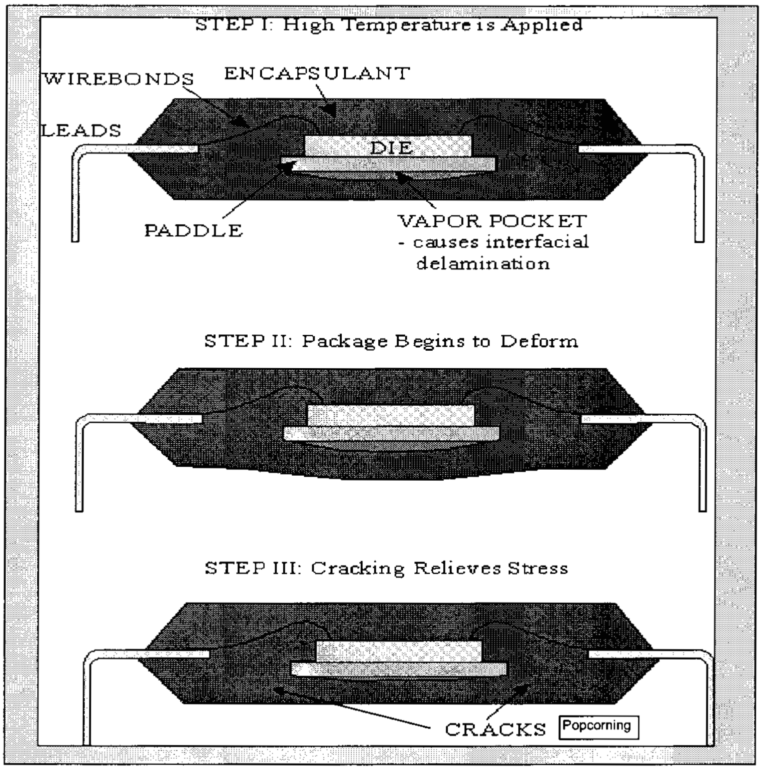


Figure 3-1. Example of absorption characteristics.

Early studies have illustrated numerous corrosion-related failures due to ionic contaminants and ingress of moisture. PEMs were also susceptible to thermally induced intermittence problems where devices suffered from open circuit failures at elevated temperatures. In recent years, improvement in molding techniques, molding compound formulations, passivation technology, and circuit layout have greatly enhanced the reliability of plastic parts, so that they are often equal to their ceramic counterparts tested under the same conditions. However, with the increasing use of surface-mount technology with large package sizes, moisture-induced package damage (such as interfacial delamination and cracking during solder reflow) can cause reliability problems. Moisture induced delamination and cracking (called popcorning) is a real problem. SMDs are more susceptible to this problem than through-hole parts because they are exposed to higher temperatures during reflow soldering. The reason for this is that the soldering operation must occur on the same side of the board as the SMD device. For through-hole devices, the soldering operation occurs under the board that shields the devices from the hot solder. Also, SMDs have a smaller minimum plastic thickness from the chip to mount pad interface to the outside package surface that has been identified as a critical factor in determining moisture sensitivity. Because of this problem, moisture sensitivity guidelines to be followed for surface mounted devices have been generated by manufactures as shown in Figures 3-2, 3-3, and 3-4 below.



A. Moisture saturates the package to a level determined by storage RH, temperature, time and plastic moisture equilibrium solubility.

B. Vapor pressure and plastic expansion combine to exceed adhesive strength of plastic bond to lead frame die pad. Plastic delaminates from pad and vapor – filled void expands, creating a characteristic pressure dome on the package surface.

C. Pressure dome collapses and crack forms emanating from boundary of delamination area at frame pad edge. Remaining void area acts to concentrate stresses in subsequent temperature cycling, leading to further crack propagation.

Figure 3-2. Example of Popcorning Events.

Vendor's MS Level Assignment	Drypack Required	Storage TH	Time Out of Drypack Allowed
1	No	30°C/90%RH	Indefinite
2	Yes	30°C/60%RH	One Year
3	Yes	30°C/60%RH	168 Hours Max
4	Yes	30°C/60%RH	72 Hours Max
5	Yes	30°C/60%RH	24 Hours Max
6	Yes	30°C/60%RH	6 Hours Max

Figure 3-3. Storage and Moisture Sensitivity Levels.

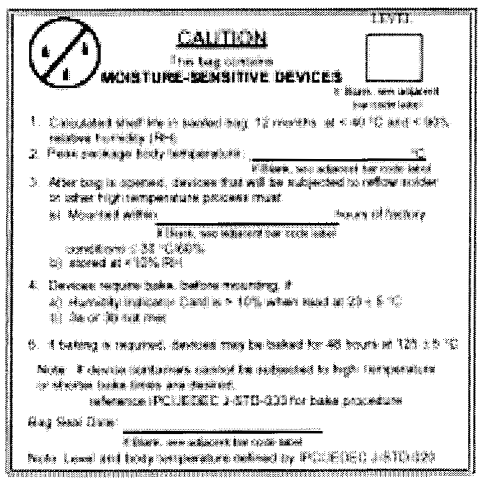


Figure 3-4. Moisture Mark Label

Section 4
Delamination of Plastic Packages

One area that impacts PEM reliability is molding compound adhesion to the various elements within the device, especially the die surface. This condition should always be considered a potential failure. This type of problem has been correlated to intermittent electrical open at high temperature and corrosion. Delamination at the wire bond can degrade the wirebonding interface due to mechanical forces on the ball bond made possible by temperature cycling. This can cause cracking of the silicon under the ball bond. Another reliability problem is die cracks that occur as a result from improper mechanical handling during the packaging process. This type of problem may not show up during electrical test but will cause a permanent failure during repeated thermal cycling during use. There are many other potential problems with plastic packages that can be detected using a nondestructive technique called acoustic micro imaging (aka C-SAM).

C-mode Scanning Acoustic Microscopy (C-SAM™) analysis utilizes reflection mode (pulse echo) technology in which a single, focused acoustic lens mechanically raster scans a tiny dot of ultrasound over the sample. As ultrasound is introduced (pulsed) into the sample, a reflection (echo) is generated at each subsequent interface and returned to the sending transducer for processing. Proper lens selection and proprietary high speed digital signal processing allow information to be gathered from multiple levels within a sample. Images can be generated from specific depths, cross sections or through the entire sample thickness and are typically produced in ten to thirty seconds. See Figure 4-1 below.

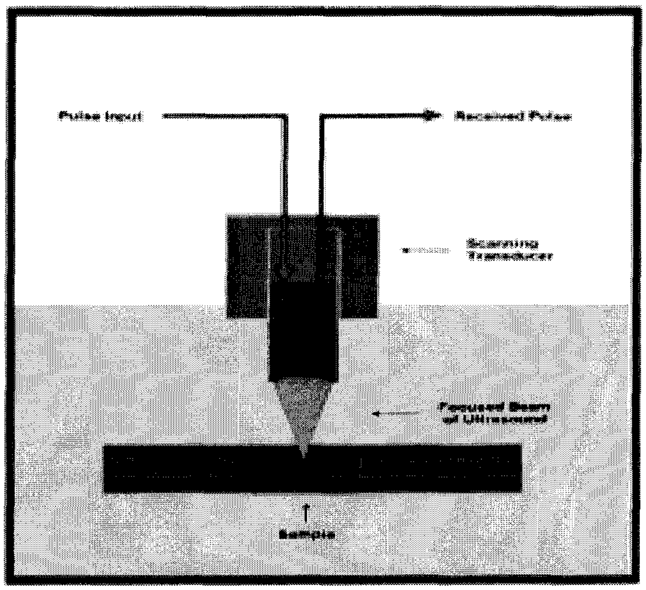


Figure 4-1. Schematic of the C-mode scanning acoustic microscope. This instrument incorporates a reflection, pulse-echo technique that employs a focused transducer lens to generate and receive the ultrasound signals beneath the surface of the sample.

Applications include nondestructive detection of delaminations between lead frame, die face, paddle, heat sink, cracks, and plastic encapsulant. The compatibility of a material is ultimately limited by ultrasound attenuation caused by scattering, absorption, or internal reflection. This technique is often used for process and quality control although it is also used for screening of devices where high reliability is desired for unique requirements such as Space applications.

Examples of C-SAM Inspection are shown below in Figure 4-2. Area in red and dark shadow area represent delamination and are suspect as potential failure.

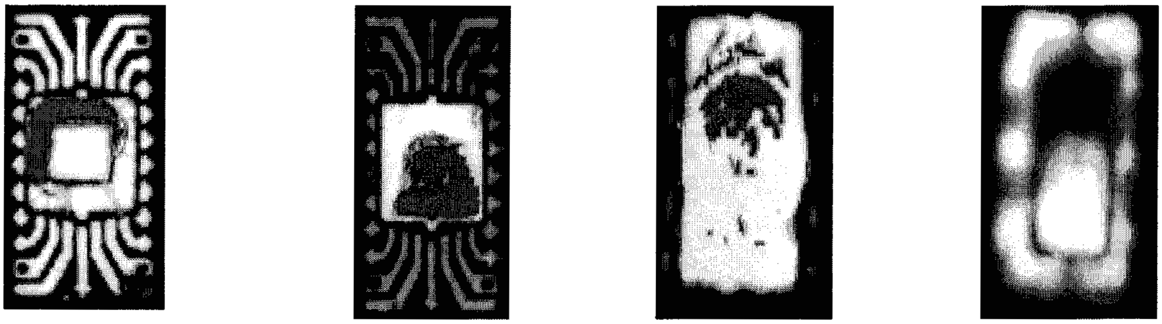


Figure 4-2. C-SAM Inspection with Evidence of Delamination

Other acoustic test modes such as A-mode, B-mode, and Through Transmission Mode are also used to detect anomalies in plastic packages. Reference IPC/JEDEC J-STD-035.

The following are typical areas for inspection of delamination using acoustic microscopy:

Type I. Delamination: Encapsulant/Die Surface

Type II. Delamination: Die Attach Region

Type III. Delamination: Encapsulant/Substrate

Type IV. Delamination: Substrate/Encapsulant

Type V. Delamination: Encapsulant/Lead Interconnect

Type VI. Delamination: Intra-Laminate Substrates

Type VII. Delamination: Heat Sink/Substrate

Other inspection anomalies include cracks/ mold compound voids associated with bond wire, ball bond, wedge bond, tab bump, tab lead.

Section 5
PEM Reliability Performance

There are many reports and data that portray that PEMs reliability has improved over the years which is undoubtedly true. There are also reports by screening houses that show there are still many part failures with today's PEMs which is also undoubtedly true. Much of the data taken and reported on is from specific manufacturers, lots, part types, unique environments, and based on reliability monitors and or periodic testing. All of this data and improvement trends do not however insure the lot in hand or actual devices in hand to build flight hardware is of a high enough reliability (very low risk) to use in Space. For some Space applications where moderate or even a high risk (very short application) is acceptable, PEMs as procured may have acceptable reliability and risk. However there is sufficient evidence that using plastic devices off-the-shelf poses serious reliability implications for flight hardware without adequate screening and or qualification.

Examples of field data being reported from different sources are shown in Figures 5-1, 5-2, and 5-3 below.

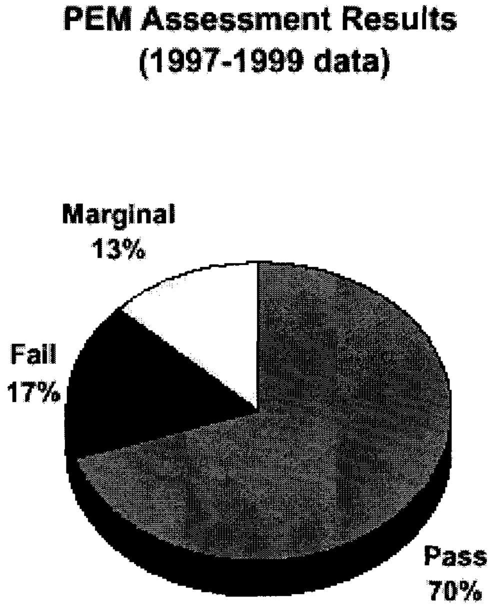


Figure 5-1. PEM Assessment Results

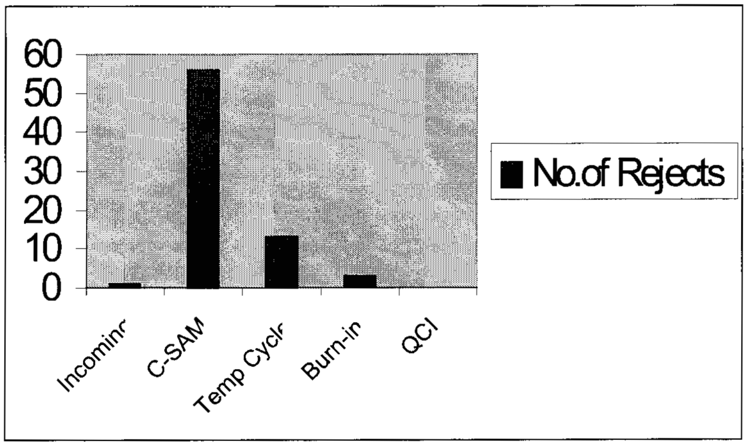
DPA RESULTS 1/99 - 3/99

31.8% TOTAL FAILURE RATE

	TOTAL	CR*	FAIL	% FAIL	IV	SEM	OTHER
MICROCIRCUIT	172	16	57	33.1	13	31	13
CAPACITOR	183	10	31	16.9	25	0	6
DIODE	175	33	77	44	67	0	10
HYBRID	27	6	13	48.1	3	1	9
TRANSISTOR	24	3	30	35.7	16	8	6
OTHER	73	4	19	26	0	0	0
TOTAL	714	72	227	31.8	124	40	44

CR* = CUSTOMER REVIEW

Figure 5-2. DPA Results 1/99-3/99



Incoming = 0.42%

C-SAM = 24.35%

Temp Cycle = 5.55%

Burn-in = 1.28%

QCI = 0.00%

Total = 31.60% (3 types)

Total = 24.8% (5 types)

Figure 5-3. Plastic COTS Upscreening Results.

Section 6
Upscreening/Qualification

Using Grade 1 parts or their equivalent should be the user's first choice when available, since reliability risk is minimal and acquisition cost is competitive. When Grade 1 parts are not available, and commercial grade is to be used, it is highly recommended that some upscreening be performed to ascertain reliability and radiation risk. Commercial parts are highly at risk when used in a high reliability application (e.g., space). In particular, plastic parts must be evaluated for package defects as well as electrical and radiation performance. Commercial parts are almost always manufactured on multiple foundry/processes, assemblies, and screened by different test facilities. Upscreening, and or qualification by the user, are expensive and can jeopardize parts due to mishandling. Great care is therefore taken in its planning and execution. Upscreening and qualification is only valid for the lot being tested and results cannot be extrapolated to other lots. This is especially true for radiation results. Performing upscreening and qualification on a part does not make it equivalent to a Grade 1 part. It does however considerably reduce risk and quantify its merit by the test results (fallout).

Manufacturers will not endorse upscreening or support the use of any commercial part beyond the commercial data sheet. This is a fundamental safety and liability problem. The potential dollar liability and adverse publicity associated with the electrical and environment risks involved when commercial plastic parts are used in military and space applications have prompted suppliers to publish disclaimers in their product literature and modify their terms of sale. *For these reasons the risk belongs to the user if parts are tested or used in a different manner than what the manufacture intended.*

Some risks associated with upscreening and qualification should be mentioned. Upscreening can give a false notion of superb reliability since much of the testing may not be as adequate as that performed by the manufacturer with their vast understanding of the part history, construction, design, and in-house reliability and performance data. Using parts outside their design performance and rating can reduce built-in reliability margins and or design robustness. There is also a potential risk of introducing latent damage during the handling and testing of devices which can compromise long term reliability. Nevertheless, upscreening has been demonstrated by JPL and others to add value by removing defective parts prior to assembly and thus improve board and system reliability.

There is often confusion and misunderstanding of the following terms and therefore some definitions commonly used are as follows:

- Upscreening - process to create a part equivalent to one of a higher quality by additional screens with specification

- Uprating - assess performance/functionality capability outside specification range (e.g. thermal uprating)

- Upgrading – process to create a part equivalent to one of a higher quality by additional screens outside specification

- Characterization – assess performance parameters against limits outside and or within specification range

- Cherry Picking – choosing parts based on some predetermined selection criteria

Many of the above terms are used interchangeably and in fact, all terms may apply to what is actually being performed during an upscreen and qualification process.

The following table shows how PEMs compare to other grades for expected upscreen fallout, the projected relative cost to a Project, and the elements included in the cost of upscreening.

Table 6-1. Mission Matrix & When to Upscreen

Generic Application	Space	Military-High Rel (Repairable Systems)	Military/ Commercial (Repairable Systems)	Commercial (Repairable Systems)
Mitigation Required for Space	No	Yes	Yes	Yes

Part Groups	NPSL Level 1 or 975 Grade 1	NPSL Level 2 or 975 Grade 2	NPSL Level 3 or Vendor Flow	Commercial
Active Parts	JAN Class S QML Class V & K "S" SCD JANS	JAN Class B QML Class Q & H JANTXV, JANJ	883 B QML Class M,N,T DESC Drawing, SMD JANTX & JAN	COTS (PEMs)
Actives DPA	No (Selective)	Yes	Yes	Yes & Construction Analysis
Actives Upgrade Screening	No	Yes	Yes	Yes
Lot Characterization Fallout Experience (excluding radiation)	<0.1%	1% to 10%	5% to 50%	3 % to 65%
	S	R	P	M & L
Passives DPA	No (Selective)	No (Selective)	Yes	Yes & Construction

Generic Application	Space	Military-High Rel (Repairable Systems)	Military/ Commercial (Repairable Systems)	Commercial (Repairable Systems)
				Analysis
Passives Upgrade Screening	No	No	Yes	Yes

Project Cost $	≤3 - 5%	>5%	>>5%	>>>5% -highly variable
Cost Elements. (radiation requirements are mission dependent)	Part Acquisition including component engineering.	Part Acquisition including component engineering. Risk Mitigation as follows: Upgrade screen per SSQ25001, Develop: software, burn-in/life test circuits; DPA, Characterization (by lot) over temperature) /Radiation (e.g. SEL, SEU, TID, Protons)	Part Acquisition including component engineering. Risk Mitigation as follows: Upgrade screen per SSQ25001, Develop: software, burn-in/life test circuits; DPA, Characterization (by lot) over temperature /Radiation (e.g. SEL, SEU, TID, Protons)	Part Acquisition including component engineering. Risk Mitigation as follows: Upgrade screen per mission requirements, Develop: software, burn-in/life test circuits; DPA, Special tests for PEMs, Characterization (by lot) over temperature /Radiation (e.g. SEL, SEU, TID, Protons)

Making Tradeoffs

Obtaining upscreen quotes and schedules from different sources are necessary for planning and meeting Project part needs. The quotes and schedules will most likely change every time they are solicited. Some consistency may exist from some sources but the business climate may be the ultimate driver as to whether quotes received are high or low. In some cases these quotes can be improved with negotiation but this must be done early in the process. Figure 6-1 below shows an example of quotes and schedules received for a part upscreen flow solicited. As shown, there is considerable variation from each of the sources. This makes the selection process critical since the quoted price and delivery must be balanced with the Project's needs (affordability and schedule). The sources have to be looked at in terms of their technical capability, past history of delivering on time, available human and capital resources, willingness to negotiate, and ability to recover from obstacles and problems. Often times the schedule overrides the cost when time is dictated by a critical launch date. When the schedule is pushed out the cost may be the only driver for making a choice. In either case there must be some recovery or contingency plan available since the best made choices can be faltered.

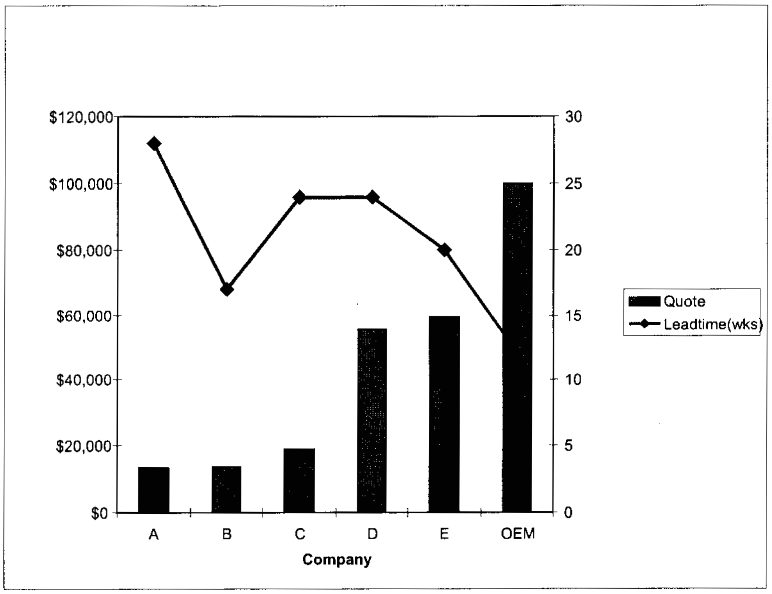


Figure 6-1. Cost vs. Schedule Quotes.

Section 7
Upscreening Test/Qualification for 1 Year Mission

Table 7-1 and 7-2 provide examples of upscreening test plans for using plastic parts in a one-year mission. The steps chosen, and the order, in which they are followed, are important to insure the reliability of the parts in their specific application. These steps address known failure mechanisms for plastic parts and mechanisms that are a potential risk given the right circumstances. The sample sizes used for the various steps are dependent on the sensitivity of the test to screen out rejects. Critical steps are always 100% of the lot tested and not based on sampling. Radiation testing (very important) is not 100% since it is a destructive test and expensive to perform. The flow and test conditions shown below can be altered if it is necessary to meet different mission objectives or priorities. The tailored approach makes the upscreening effective and gives the highest value to meeting the customer's needs. The two tables below are examples of such tailored approaches.

Table 7-1. Example of PEM Microcircuit Upscreening Flow for 1 Year Mission.

Step	Screen	Required	Reject Criteria (rejects reviewed by specialist)	SS	Comments
1	Parts List	Review of project's parts list including manufacturers and part types. Review against project drivers and requirements.	Report on known part or vendor problems; Make recommendations and what further course of action should be taken by projects with cost estimate.	N/A	Requires specialist
2	Radiation	Test to project requirements	Any parts failure to meet data sheet parametrics per radiation specified. Data to be recorded.	0/22 per lot/ or same date code (LTPD=10)	**Destructive test used on flight parts**
3	DPA	SEM / Cross section of steps,via, contacts.	Any abnormal processing especially with metalization. Thinning, voids, notches, or apparent abberations will be recorded.	4 per lot/ or same date code (0/22 per mil std 105)	**Destructive test used on flight parts**
4	Electricals	Test to data sheet at room temperature.	Any parts failure to meet data sheet parametrics at room temperature. Data to be recorded.	100%	Non-destructive test used on flight parts
5	Temp Cycle	Ta = Project requirements	Mil-Std-883 TM-1010, 10 cycles	100%	Non-destructive test used on flight parts
6	C-SAM	Inspect for delamination and or cracks between LF & MC, die surface to MC, die attach to MC, die pad to MC.	Delamination, voids, or cracks: > 10% of area. Rejects will be recorded.	100%	Non-Destructive test used to screen flight parts
7	Electricals	Test to data sheet or system operating temperature range; whichever is greater	Any parts failure to meet data sheet parametrics at room temperature. Data to be recorded.	100%	Non-destructive test used on flight parts
8	Burn-In	Dynamic test at 240 hrs min. at maximum data sheet or system operating temperature.	Any parts failure to meet data sheet parametrics over the temperature range. Data to be recorded. (ref. Mil-Std 883, Method 1015.7 cond. D.)	100%	Non-Destructive test used to screen flight parts. A critical review of vendors reliability data, if available, may be substituted for BI.
9	Electricals	Test to data sheet or system operating temperature range; whichever is greater	Any parts failure to meet data sheet parametrics. Data to be recorded.	100%	Non-Destructive test used to screen flight parts

The following steps are optional and are dependent on the mission requirements.

10	ESD	>2000V	Test to JESD22-A114-A and JESD22-C101	0/11 (LTPD=20)	QCI (optional)- **destructive test**
11	Outgassing	TML<1%; CVCM<.1%; WVR<.30%	Test to ASTM E595.93	0/11 (LTPD=20)	QCI (optional)- **destructive test**
12	85/85 (THB)	Ta = 85C, RH = 85% Vdd Rated	Test to JEDEC Std 22-B TM-A101	0/22 (LTPD=10), 0/45 (LTPD=5)	QCI (optional)- **destructive test**
13	Temp Cycle	Ta = storage conditions	Mil-Std-883 TM-1010, cond. C 500 cycles Inspect with C-SAM	0/22 (LTPD=10), 0/45 (LTPD=5)	QCI (optional)- **destructive test**
14	Add any special test requirements	TBD	TBD	TBD	If necessary

Notes:

1) Total units required for destructive testing including DPA, Radiation, and QCI = TBD
2) Steps 10, 11, 12, 13 are used if a supplier is unknown, inadequate data is available from the supplier, or failures in steps 5-11 warrant further evaluation and qualif
3) Any step or sequence may be modified at the discretion of the specialist and agreement from the Project (cost & schedule may be impacted).
4) Parts used for testing/or QCI are the same as the flight parts
5) No PDAs are specificed for any step; accept or reject is decided by the specialist and designer upon review of the test results.
6) This flow will be adapted for each part type as requirements dictate.

Table 7-2. Example of PEM Transistor Upscreening Flow for 1 Year Mission.
The cost and weeks (column)s for each step are to be used for the initial planning and making adjustments, tradeoffs, etc. that may be necessary by a Project. The test and screen results (column) are provided to allow a final record for all tests completed.

Step	Screen	Required	Reject Criteria	Qty	Cost	wks	Comments	Test/Screen Results
1	DPA	SEM / Cross section of steps,via, contacts.	Any abnormal processing especially with metalization. Thinning, voids, notches, or apparent abberations will be recorded.	4			Destructive test ; samples taken from Flight lot	
2	Serialization	Laser Serialization	N/A	100				
3	Electricals	Test to data sheet @ -105C, +25C, +105C	Any part failing to meet data sheet parametrics at the temperatures specified. Data to be recorded	100			Non-destructive test used to screen flight parts	
4	Temp Cycle	Ta = -105C to +105C	10 cycles	100			Non-destructive test used to	
5	X-Ray	Mil-Std-883 method 2012 two views	Photographs will be reviewed by the Specialist	100			screen flight destructive test used to	
6	C-SAM (work to be done at Sonoscan)	Inspect for delamination and or cracks between LF & MC, die surface to MC, die attach to MC, die pad to MC.	Delamination, voids, or cracks: > 10% of area. Rejects will be identified and recorded. Photographs will be reviewed by the Specialist	100			screen flight destructive test used to screen flight parts	
7	Electricals	Test to data sheet @ -105C, +25C, +105	Any part failing to meet data sheet parametrics at the temperatures specified. Data to be recorded.	100			Non-destructive test used to screen flight parts	
7a	HTRB(gate stress)	24 hrs at 100C; Vgs=80% of max rating		100				
7b	Electricals	Test to data sheet @ -105C, +25C, +105	Any part failing to meet data sheet parametrics at the temperatures specified. Data to be recorded/reviewed for outliers	100			Non-destructive test used to screen flight parts	
8	Power Burn-In	Circuit used is per application (72hrs at +105C)	N/A	100			Non-destructive test used to	
9	Electricals	Test to data sheet @ -105C, +25C, +105C;	Any part failing to meet data sheet parametrics at the temperatures specified. Data to be recorded/reviewed for outliers	100			screen flight destructive test used to screen flight parts	
10	Mini Life (Power Burn-in)	Circuit used is per application (72hrs at +105C) Assumes max +40C operating temp.	N/A	10 (from parts passing step 9)			Non-Destructive test used to qualify flight	
11	End Point Electricals	Test to data sheet @ -105C, +25C, +105C;	Any part failing to meet data sheet parametrics at the temperatures specified. Data to be recorded/reviewed for outliers	10			parts. Destructive test used to qualify flight	

Section 8
Budgetary Cost Quotes

The cost associated with upscreening and or qualifying PEMs is highly variable depending on the vendor doing the testing and the requirements included in the upscreening. To attain a cost-effective upscreening, budgetary quotes are recommended. Costs can add up quickly depending upon what is included in the upscreen. Therefore, only steps that are necessary to insure mission reliability should be carried out. Adding steps that are optional should only be considered under extenuating circumstances, and only if no information is available. Two expensive steps are generating test software and building custom burn-in boards. It is advisable to select vendors that have baseline software that can be modified to test the device. Burn-in boards should be designed to simulate actual device applications (dynamic) rather than using generic ones. Generic boards do not adequately stress devices for mission reliability even though they may typically cost less.

Vendors should be chosen for their capability, past performance, technical acumen, having the necessary equipment (state-of-the-art), and willingness to accommodate. Lowest cost is not always prudent, especially if problems develop after the contract is in place. Since a custom upscreening flow is recommended for flight hardware it must be clear to the vendor exactly what requirements are to be carried out. Visiting the vendor and performing a mini audit is useful to validate their in-house capability and to meet with engineers and schedulers. If automatic tracking of material is available (for example, the Internet), it is advisable to establish a means for real-time access to material in process.

Schedules of completion are typically critical and should allow for slippage. Typically a non-recurring cost is associated with generating software and constructing burn-in boards, unless it is buried in the unit cost. All costs should be clearly stated in the budgetary and final quote. A data package is imperative and should include read and record. Electronic format is preferred.

Section 9
Test/Qualification Matrix
Imposed for Different Mission Durations

The test and or qualification used to insure reliable plastic parts in space applications are tailored to meet specific mission requirements. This means every critical aspect of the parts environment, temperature usage, stresses, and expected performance are reviewed to achieve the proper upscreening and or qualification. Below are examples of three different types of mission requirements established for 1, 5, and 15 years with the upscreening and or qualification imposed. A 10 year mission has not yet been defined but would be similar. These flows are not generic but should be modified as necessary for each mission type and its requirements. In this way the optimum flow and value is obtained to insure reliability, performance, and success.

Table 9-1 .

JPL Flow		COTS (1)++			COTS (5)++			COTS (10)++			COTS (15)++	
Project		(Mars01-Pancam)			(Galex)						(X2000)	
Mission Time		<1 yr (1500hrs)			1-5yr (25000hrs)			5-10yr (87600hrs)			10-15yr (131400hrs)	
DPA (JPL)			ss			ss			ss			ss
1.External Visual	X	Package	4	X	Package	4				X	Package	4
2.Radiographic	X	Wire Bonds	4	X	Wire Bonds	4				X	Wire Bonds	8
3.Internal Visual	X	Die	4	X	Die	4				X	Die	8
4.SEM												
a. Metalization	X		4	X		4				X	All layers	8
b. Glassivation	X		4	X		4				X	Thickness, pinholes	8
c. Cross-sections										X	Contacts, Vias, Steps	4
5. Bond Pull		Method 2011			Method 2011					X	Method 2011	2
UpScreen (flow)												
5.Electricals 1	X	+25C; -55C	100%	X	-55C;-15C;+55C;+70C	100%				X		100%
5A. Life Test				X	2000 hrs at +70C(ref step12)	10						
6.Temperature Cycle	X	-60C to +25C (10cy)	100%	X	-60C to +60C (10cy)	100%				X		100%
6A. X-Ray				X	Mil-Std-883 meth 2012	100%				X	Mil-Std-883 meth 2012	100%
7.C-SAM	X	Top, Bottom, Thru	100%	X	Top, Bottom, Thru	100%				X	Top, Bottom, Thru	100%
8.Electricals 2	X	+25C; +55C	100%	X	-55C;-15C;+55C;+70C	100%				X		100%
9.Dynamic Burn-in(ELFR)	X	5V for 72 hrs (+55C)	100%	X	336 hrs (+70C)	100%				X		100%
10.Electricals 3	X	+25C; -55C	100%	X	-55C;-15C;+55C;+70C	100%				X		100%
Qualification												
11.Life Test (HTOL)	X	5V for 72 hrs (+55C)	10	X	2000 hrs (+70C)	22				X		22
12.Electricals	X	+25C; -55C	100%	X	-55C;-15C;+55C;+70C @	100% 500,1000,1500,		2000 hr read points		X		100%
14. Post Life Bond Pull												
15. Outgassing	X	ASTM E 595-93	2							X	ASTM E 595-93	2
16. ESD										X	HBM	2
17. PDA												
18. Preconditioning		JESD22-A113-A										
19. Traceability (Date C.)										X	Wafer Lot preferred	
20. Traceability (QML)										X	QML Vendor preferred	
21. Current Density Cal.										X	Worst Case(see step 4a)	1
22. Temperature Cycle										X	1000 cy -50C to +150C	22
23. Power Cycling										X	1000 Cycles@ max rated power	22
24. Data Retention										X	1000 hrs@+150C	4
25. HAST										X	96 hrs@+130C/85% RH	22
Device/Pack. Handling												
22. Moisture Sensitivity	X	IPC-SM-786A	100%	X	IPC-SM-786A	100%				X	IPC-SM-786A (level 1,2,or3)	100%
23. ESD	X	Precautions Required	100%	X	Precautions Required	100%				X	Precautions Required(min 300v)	100%
24. Contamination										X	Precautions Required	100%
Documentation												
25.Data R/R (Review)	X	Failures/Delta Shifts	100%	X	Failures/Delta Shifts	100%				X	Failures/Delta Shifts	100%
26. QA C of C	X		By Lot	X		By Lot				X		By Lot

Failure Mechanisms Detected with Test/Qualification Matrix

Screening and qualification are used to eliminate rejects and mitigate risk of certain types of failure mechanisms. Below are 24 examples of failure mechanisms and modes that can be detected with comprehensive screening and qualification.

Ionic contamination	Al Electromigration
Mechanical fatigue	Corrosion (moisture)
Oxide failure(TTDB)	Cracked Die
Outgassing	Data retention
Popcorning	Degraded ball bonds
Purple Plague	Degraded parametrics
SEL	Delamination
SEU	Electrical Latch-up
Solder fatigue	EOS
TID	ESD
Wire sweep	Ex Temperature Failures
Shorts, Floating nodes	Infant Mortality

Some Failure Mechanism/Term Definitions are:

Ionic contamination – Any contaminant which exists as ions and when in solution increases electrical conductivity.

Outgassing - Gaseous emission from a material when exposed to reduced pressure and /or heat.

Popcorning - Expression which is used to describe a phenomenon which causes package cracking in PEMs (typically surface mount packages) during soldering to boards.

ESD - (Electric Static Discharge). Transfer of charge from one surface to another by static electricity.

EOS – Electrical Overstress

Delamination – A separation between the laminated layers of a base material and/or base material and overlaying coating.

Ball Bond – The connection of a bond wire to the bondpad of a microcircuit. The end of the wire is melted into a ball which is then diffusion bonded to the metallized pad using heat and pressure.

Infant Mortality – Failures in a device population which occur early in the life of the population.

Wire Sweep – Term used to describe the permanent movement or bending over of interconnection wires inside a PEM which can occur during the molding process.

Electromigration – Migration of metal within interconnect lines which occurs when the momentum transfer of electrons is sufficient to move metal ions through the line. Factors such as high current density regions accentuate migration.

Purple Plague - An intermetallic compound between gold and aluminum ($AuAl_2$).

SEL (Single Event Latchup) – A loss of device functionality due to a single event typically the result of a parasitic SCR structure in an IC becoming energized by an ion strike.

SEU (Single Event Upset) – A "soft error", change of logic state, or a bit flip caused by alpha particles or cosmic rays as they pass through a device.

TID – Total Ionizing Dose, accumulation of absorbed ionizing radiation specified at a particular dose rate exposure at 25°C.

TDDB - Time Dependent Dielectric Breakdown (typically refers to device oxide wearout)

Section 10
Summary & Concluding Remarks

The next generation of spacecraft has the formidable challenge to revolutionize spacecraft design and construction. Specific objectives include affordability, significant reduction in mass and volume, and high integration of on-board operations using ultra micro miniaturization of electronics and complex computing functions offered only with Commercial Off-the-Shelf (COTS) parts and technologies. Plastic Encapsulated Microcircuits (PEMs) fall into this classification. Determining what parts and technologies can reliably accommodate this end is no easy task. Informed planning and risk management are essential to building a reliable spacecraft. Any unknown risk associated with using advanced electronic technologies and COTS parts can result in a significantly compromised or even a catastrophic mission. To mitigate such events, it is necessary to purchase the best available and qualified parts that meet mission requirements first such as Grade 1. When it is necessary to go outside and beyond what is available and perform additional risk mitigation, a careful and exacting plan needs to be followed.

Office 514, Electronic Parts Engineering, has repeatedly demonstrated to different Projects using PEMs that a viable tailored risk mitigation plan can be achieved that will significantly reduce their risk if followed. More information can be found at the web site shown below at http://cots.jpl.nasa.gov.

Appendix 1
Reference Documents

Reference Documents for Plastic Testing/Qualification

JEDEC-STD-JESD22-A112	Moisture-Induced Stress Sensitivity
JEDEC-STD-JESD22-A113-A	Preconditioning of Plastic Surface Mount Devices Prior to Reliability Testing
JEDEC-STD-JESD22-A104	T/C "Temperature Cycling"
JEDEC-STD-JESD22-A108	HTOL "Bias Life"
JEDEC-STD-JESD22-A110	HAST
JEDEC-STD-JESD22-A102	Autoclave
JEDEC-STD-JESD22-A101	85/85 "Steady-State Temperature Humidity Bias Life Test"
JEDEC Standard 26	Proposed "General Specification for Plastic Encapsulated Microcircuits For Use in Rugged Applications"
JESD22-C101	Field Induced CDM Test Method for ESD
EIA/JESD22-A114-A	ESD Sensitivity Testing Human Body Model
EIA/JESD22-A115-A	ESD Sensitivity Testing Machine Model
Mil-Std-883, Method 1010	Temperature Cycle
Mil-Std-1580	"Destructive Physical Analysis for EEE Parts"
ASTM E595 93	Test Method for TML and CVCM (outgassing)
ASTM D648 95	Test Method for Deflection Temperature of Plastics
ASTM D696	Coefficient of Thermal Expansion
ASTM D543	Chemcial Resistance
ISO 75-1-1993	Plastics-Determination of Temperature of Deflection Under Load-Part 1:General Test Method
ANSI / IPC-SM-786	Recommended Procedures for Handling of Moisture Sensitive Plastic IC Packages

Appendix 2
PEM Mitigation Recommendations in Space Applications

Some Recommended DO's

1. Use rigorous qualifications, extended screening, and burn-in as required.
2. Design for lowest practicable operating voltage and temperature (derating).
3. Use board assembly "preconditioning" such as solder reflow prior to qualification.
4. Use non-aggressive, no-clean, fluxes in board assembly to eliminate corrosives.
5. Perform temperature cycle as part of qualification (important for larger chips i.e. >250 mils/side).
6. Maintain low relative humidity environment (<0.1% moisture before assembly and/or make unit in a dry nitrogen purge oven for 24 hours at 125C +-5C before assembly)
   (Time can vary depending on package type).
7. Stay within manufacturer operating temperature ratings.
8. Use low-stress mold compounds (especially for high pin count, large die).
9. Avoid excessive handling.
10. Use dry bags for storage control.
11. Use ruggedizing solutions when necessary.
12. Perform completed radiation characterization.
13. Qualify molding compound changes.
14. Perform DPA.
15. Perform Scanning Acoustic Microscopy evaluation at component level.
16. Perform Scanning Acoustic Microscopy evaluation after board assembly.
17. Stay below manufacturer's rated junction temperature (power consumption).

Appendix 3
Recommended DPA Steps for Plastic Packages

Destructive Physical Analysis (DPA) is routinely used by the aerospace and automotive industry in order to qualify electronic components. Many applications use DPA and or qualification to determine the quality and thereby increase the reliability of product for specific applications. There are no DPA standards for PEMs. However there are military standards test methods and best commercial practices for processes that are used to determine a minimum reject criteria. DPA is highly recommended for PEMs with significant lot sampling.

External Visual	Mil-Std 883 Method 2009
External Photo	
X-ray	Mil-Std 883 Method 2012
ESD Sensitivity	Mil-Std 883 Method 3015
Internal Visual	Mil-Std 883 Method 2010
Internal Photo	
SEM	Metalization (Steps, Contacts, Vias) Mil-Std 883 Method 2018
Bond Pull	Mil-Std 883 Method 2011
EDS (Phosphorous in glass)	< 4%
Passivation(s) Identification	Type and thickness
EDS (Cu, Si in metal)	1% to 1.5% Si; 0.5% to 1% Cu
EDS (Bromine, Chlorine)	Allowable limits vary by process

Appendix 4
Generally Accepted Qualification Tests for Plastic Encapsulated Microcircuits

Caution: only for devices designed to perform under these conditions/or qualified by the manufacturer

TEST	**MINIMUM CONDITIONS**
Preconditioning (before TC, and THB or HAST)	EIA JESD-22-A113
Temperature Cycle Air to Air	EIA JESD-22-A104 500 cycles –65°C to +150° or 1000 cycles –55°C to +125°C
Life Test	EIA JESD-22-A108 1000 hours @ +125°C or equivalent, max op. bias
Temperature Humidity Bias (THB)	EIA JESD-22-A101 1000 hours @+85°C/85% RH, nominal bias
Highly Accelerated Stress Test (HAST)	EIA JESD-22-A110 96 hours @ +130°C/85%RH
Autoclave	EIA JESD-22-A102 96 hours @ +121°C/15 PSIG
Moisture Sensitivity Classification (SMD)	EIA J-STD-020A
Data Retention (NVM)	1000 hours @ +150°C
Solderability	MIL-STD-883, Method 2003
Mark Permanency	MIL-STD-883, Method 2015
Lead Fatigue	MIL-STD-883, Method 2004

Latch-Up	EIA/JEDEC-78
ESD HBM	MIL-STD-883, Method 3015
Electrical Performance Characterization	Per Application/Use Environment
Radiation Performance Characterization	Per Application/Use Environment

Appendix 5
PEMs Reference Literature

Additional information on PEMs can be found in the literature sources listed below:

[1] Reliability Applications of Plastic Encapsulated Microcircuits, Reliability Analysis Center, Rome, NY

[2] Fundamentals of Plastic Encapsulated Microcircuits (PEMs) for Space Applications, Goddard Space Flight Center, National Aeronautics and Space Administration, February, 1995

[3] Plastic Package Availability Program, Technical Enterprise Team Defense Logistics Agency, Ft Belvoir, VA, November, 1995

[4] 5^{TH} Annual Commercial and Plastic Components in Military Applications Workshop, Naval Surface Warfare Center, Crane Division, Crane, Indiana, November, 1996

[5] Advanced Plastic Encapsulated Microelectronics, CALCE, College Park, MD, August, 1997

[6] Plastic Encapsulated Microelectronics, Michael G. Pecht, Luu T. Nguyen, Edward B. Hakim, John Wiley & Sons Inc. 1995

[7] A Case Study of Plastic Part Delamination, Semiconductor International, Kerry Oren, ITT Aerospace/Communications, Fort Wayne, Ind. April, 1996

[8] Correlation of Surface Mount Plastic Package Reliability Testing to Nondestructive Inspection by Scanning Acoustic Microscopy, T.M. Moore, R. McKenna, S.J. Kelsall, Texas Instruments Inc, IEEE/IRPS, 1991

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[10] Acoustic Microscopy, Lawrence W. Kessler, ASM International, 1989

[11] Frequently Asked Questions About PEM Reliability, W.L. Schultz, S. Gottesfeld, Florida LOG 98 with PEM Consortium, Harris Semiconductor, Orlando, Florida, February, 1998

[12] Plastic Encapsulated Microcircuits, M, Cohen, Aerospace Corporation

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[14] Reliability Considerations for Using Plastic-Encapsulated Microcircuits in Military Applications, William L. Schultz, Sheldon Gottesfeld, Harris Semiconductor, Melbourne, Florida, September, 1994

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[17] Upscreening Commercial ICs – A Semiconductor Manufacturer's Perspective, Stephen R. Martin, Texas Instruments Inc. 1997

[18] The Reliability of Plastic Encapsulated Microcircuits and Hermetically Sealed Microcircuits in MICOM Missiles, Dr. Noel E. Donlin, Research, Development and Engineering Center, Redstone Arsenal, Al, February, 1995

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